



COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

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Ward J. Oates
COMMISSIONER OF HIGHWAYS

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

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P. 4. 2.

MEMO TO: D. V. Terrell
Director of Research

The attached report, "Skid Prevention Studies in Kentucky," by J. H. Havens was prepared for the First International Skid Prevention Conference, held at the University of Virginia in September, 1958. It is primarily a summary of studies conducted by the Research Division in this general field.

Several of the items discussed have been previously reported to the Kentucky Department of Highways Research Committee. This is the first reference to the friction measuring load cell mounted in the tie rod of our experimental vehicle. We are presently using this equipment to measure frictional resistance of pavement and bridge deck surfaces. It appears that we will be able to duplicate stopping distance friction values by this method.

This report is submitted for the record and files of the Research Committee. No oral presentation has been planned.

Respectfully submitted,

A handwritten signature in cursive script, appearing to read "W. B. Drake".

W. B. Drake
Associate Director of Research

WBD:dl
Enc.
cc: Research Committee
Bureau of Public Roads (3)

SKID PREVENTION STUDIES IN KENTUCKY*

by

James H. Havens
Assistant Director of Research
Kentucky Department of Highways

SYNOPSIS

Laboratory apparatus, consisting essentially of a torque generator and a torque meter, in which a rubber annulus is driven against a plane surface of a rock core or pavement specimen, as in an ordinary friction clutch, was used to study variations in the coefficients of friction with respect to texture and material characteristics. Dry friction coefficients were found to be rather high in magnitude and fairly constant throughout wide variations in surface textures. In contrast, wet friction coefficients were very high for rough textures but very low for polished surfaces. Wet friction values correlated in an approximately hyperbolic manner with 60-degree specular reflectivity. Limestones were found to polish readily whereas sandstones tended to undergo coarse wear during preparation of the surfaces.

Experiences with sand-asphalt mixes, blends of limestone coarse aggregates and silica sands, and sandstone aggregates are briefly described.

Recent experiments in the adaptation of an automobile for monitoring pavement slipperiness are also described.

*Prepared for the First International Skid Prevention Conference,
University of Virginia, September, 1958.

INTRODUCTION

The implications from the classical concepts of friction are:

1. That the force of friction, frictional resistance, is independent of apparent contact area but is directly proportional to normal load and to actual contact area.
2. That the actual contact area is directly proportional to normal load - applicable to most elastic and plastic type of materials.
3. That the force required to slide one surface against another, force of friction, must equal the fundamental shear resistance of the material being sheared, multiplied by the actual area being sheared.
4. That the sliding resistance between surfaces perfectly separated by fluid, or lubricant, would be independent of normal load but directly dependent upon the viscosity of the lubricant, area, and velocity gradient.
5. That the frictional resistance between imperfectly lubricated surfaces, though small, is directly proportional to normal load and actual contact area and is equal to the shear resistance of the material being sheared, multiplied by the actual area being sheared.

These implications prompted the Research Division of the Kentucky Department of Highways to instigate a basic study of the frictional resistance available between tire-tread rubber and two locally available, widely differing paving aggregates (1). Quasi-elastic characteristics of rubber suggested a high degree of compliability with pavement surface textures at ordinary tire contact pressures and that contact would be unattended by permanent yielding of either the rubber or pavement asperities. Hence, loads should be supported almost entirely by quasi-elastic stress-strain; and these inherent contact characteristics of the rubber suggest very high susceptibility to lubrication.

On a phenomenological basis, at least, it was concluded that a clean, dry pavement surface comprised largely of aggregate would always exhibit near-maximum friction regardless of the texture of the contact surface. Thus, with respect to tire rubber, frictional resistance of clean, dry pavements seemed to be fairly independent of texture. In contrast, it was concluded that loss of traction on a wet pavement is due entirely to lubrication effects; and, while wet friction seemed to be fairly independent of the identity of the aggregate, it is extremely dependent upon the texture and porosity of the contact surface. Likewise, the mineralogical and lithological characteristics of the aggregates would largely determine the natural texture, type of wear (coarse or fine) which the aggregate will undergo in roadway service.

The two types of aggregate studied were limestones and sandstones. Dense, fine-grained, crystalline limestones were found to polish rather easily while sandstones, being largely quartz grains bound by much weaker matrix or cement, tended to undergo coarse wear, and always exhibited higher wet friction values.

Other details and observations from the study were reported at the 37th Annual Meeting of the Highway Research Board, January, 1958. The purpose of the present report is to present additional details pertaining to the method of testing, instrumentation, and data.

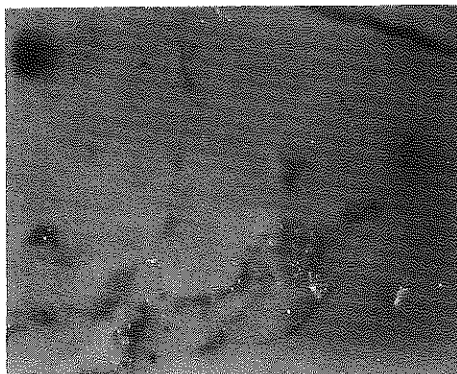
METHODS OF TESTING

In the original study, two series of rock cores, 4 in. in diameter and $2\frac{1}{2}$ to 3 in. in height, were used as samples. One series represented typical variations in limestones available as aggregate throughout about two-thirds of the area of Kentucky, while the other series represented typical variations in sandstones prevailing throughout the remaining one-third of the State. The basic intent was to establish the extreme values of wet and dry friction with respect to extreme variation in texture of the aggregates and, thereby, to test the validity and application of general friction theory. In addition, it was expected that the process of polishing and preparing the surfaces of the samples would reveal valuable information regarding susceptibility to polishing and wear characteristics.

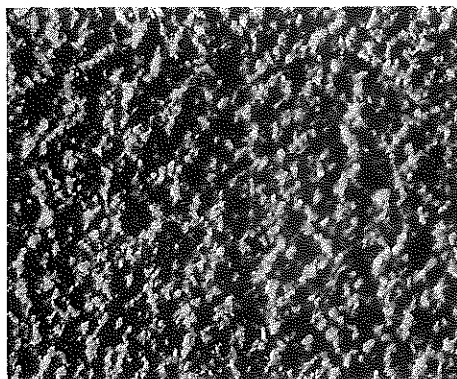
Preparation of Surfaces

The end-faces of the rock cores were sawed nearly perpendicular to the longitudinal axis, then ground against a wheel faced with No. 40 aluminum oxide abrasive paper to remove any rough edges or ridges. In order to assure evenness of the plane surfaces, each face was then ground in a slurry of coarse carborundum against plate glass. This was followed by fine carborundum and finally with levigated alumina. The final polishing was accomplished with an 8-in. diameter buffing wheel faced with heavy gauge cotton duck saturated with No. 3 Alumina. Final polishing was continued until a maximum 60-degree specular reflectivity or gloss reading was obtained. Wet and dry friction measurements were obtained from these samples in their most polished condition. Afterwards they were roughed

TYRONE
LIMESTONE



Polished (10 X)

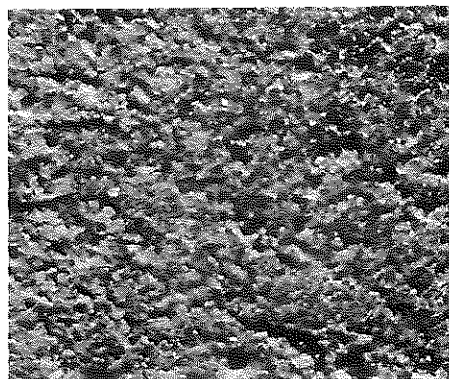


Rough (10 X)

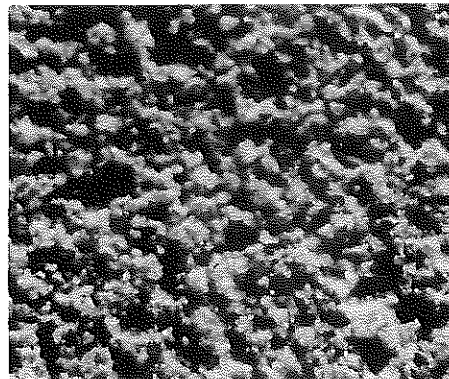


Thin Section (103 X)

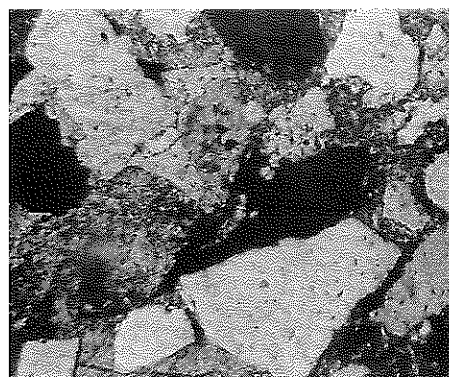
GRAYWACKE
SANDSTONE



Polished (10 X)



Rough (10 X)



Thin Section (103 X)

Fig. 1. Photomicrographs of Prepared Specimens
of Limestone and Sandstone

again with No. 150 Carborundum and then with No. 80 Carborundum against plate glass and similar measurements made.

Contrasting features of the Limestones and Sandstones are illustrated in Figure 1.

60-Degree Specular Reflectivity Measurements

As a means of evaluating the comparative and maximum degree of polish obtained, a 60-degree gloss meter, illustrated in Figures 2 and 3, was used. This, of course, required that each surface be as nearly planar as possible. All measurements were made relative, percentage-wise, to a high-quality, first-surface mirror and were not corrected for differences in absorption of the samples. The highest values were in the order of 10 percent and were obtained from dense, fine-grained limestones. The maximum value obtained from the sandstones was 4.3 percent.

Reflectivity values were found to correlate in an approximately hyperbolic manner with wet friction values as illustrated in Figure 4.

Roughening of the surfaces with No. 150 and No. 80 grit Carborundum produced completely diffusing-type surfaces and gave a marked increase in the coefficient of wet friction.

Since reflectivity measurements of this type are inherently limited to plane surfaces and since aggregate particles in a pavement would likely tend to wear or polish in such a way as to produce curved surfaces, specular reflectivity measurements of pavement would probably prove to be meaningless. Consequently, such methods are limited to use in the laboratory and to prepared plane surfaces.

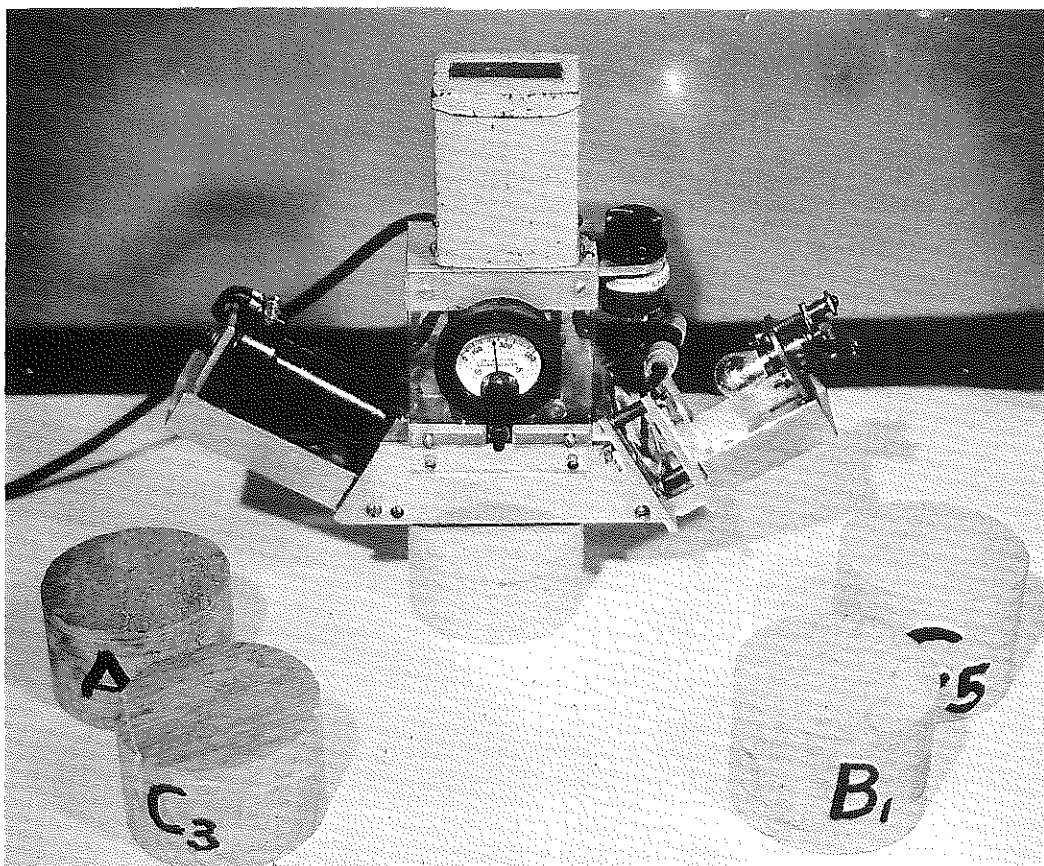


Fig. 2. Sixty-Degree Reflectometer in Position for Measuring Surface Gloss of Specimen

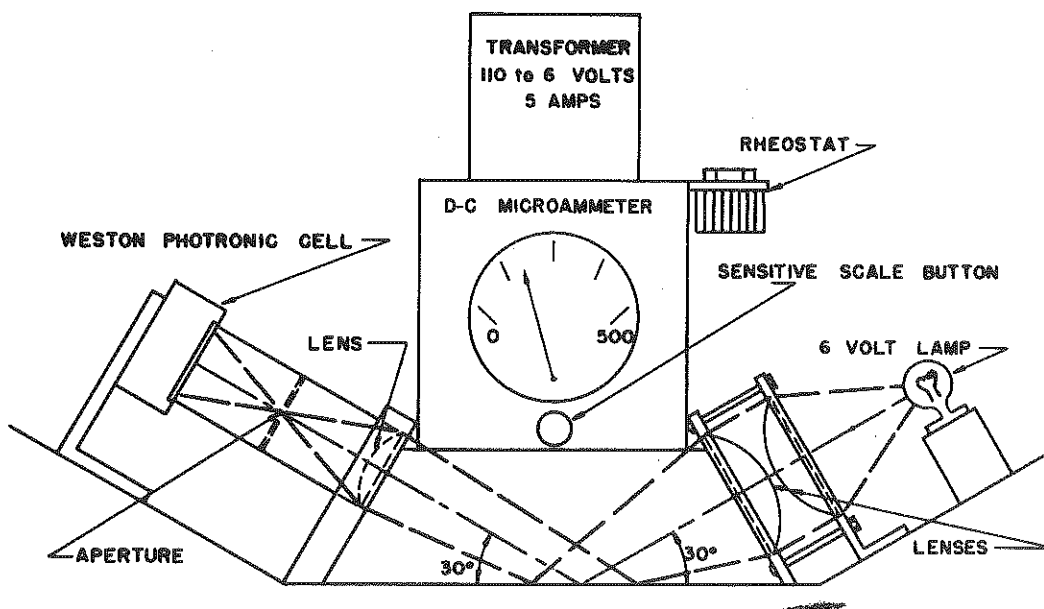


Fig. 3. Schematic Drawing of 60-Degree Reflectometer

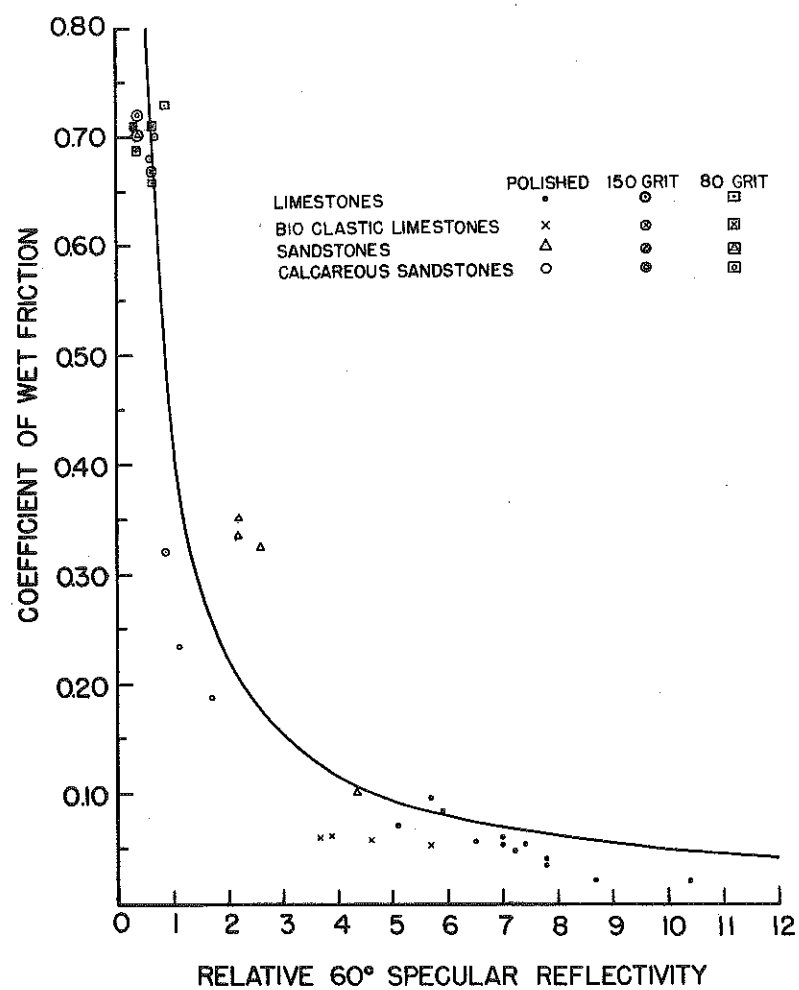


Fig. 4. Graphical Relationship between 60-Degree Specular Reflectivity of Prepared Plane Surfaces of Rock Specimens and Coefficients of Wet Friction, with Respect to Rubber

Friction Measurements

Coefficients of friction were determined by rotating a rubber annulus against the plane surface of the rock cores and measuring the amount of torque transferred to the sample at various normal loads. The apparatus, illustrated in Figure 5, consisted essentially of a torque generating system driving a vertical spindle to which the rubber annulus is affixed by means of a face-plate. The sample was affixed by means of a chuck, to the end of a spindle floating against a pneumatic cylinder. Thus, the contact between the rubber annulus and the sample acted in the same manner as a friction clutch. The torque induced in the floating spindle was measured as moment of tangential force; and, by expressing the normal load as moment of normal load, or load in pounds times the mean radius of the annulus, coefficients of friction were calculated by the formula:

$$f = \frac{M}{P \left(\frac{r_2 + r_1}{2} \right)}$$

Wet friction measurements were made by simply flooding the surface of the sample with water.

The apparatus, as illustrated, is probably more complicated than necessary, and the essential elements of the system might be rigged more easily on an ordinary drill press.

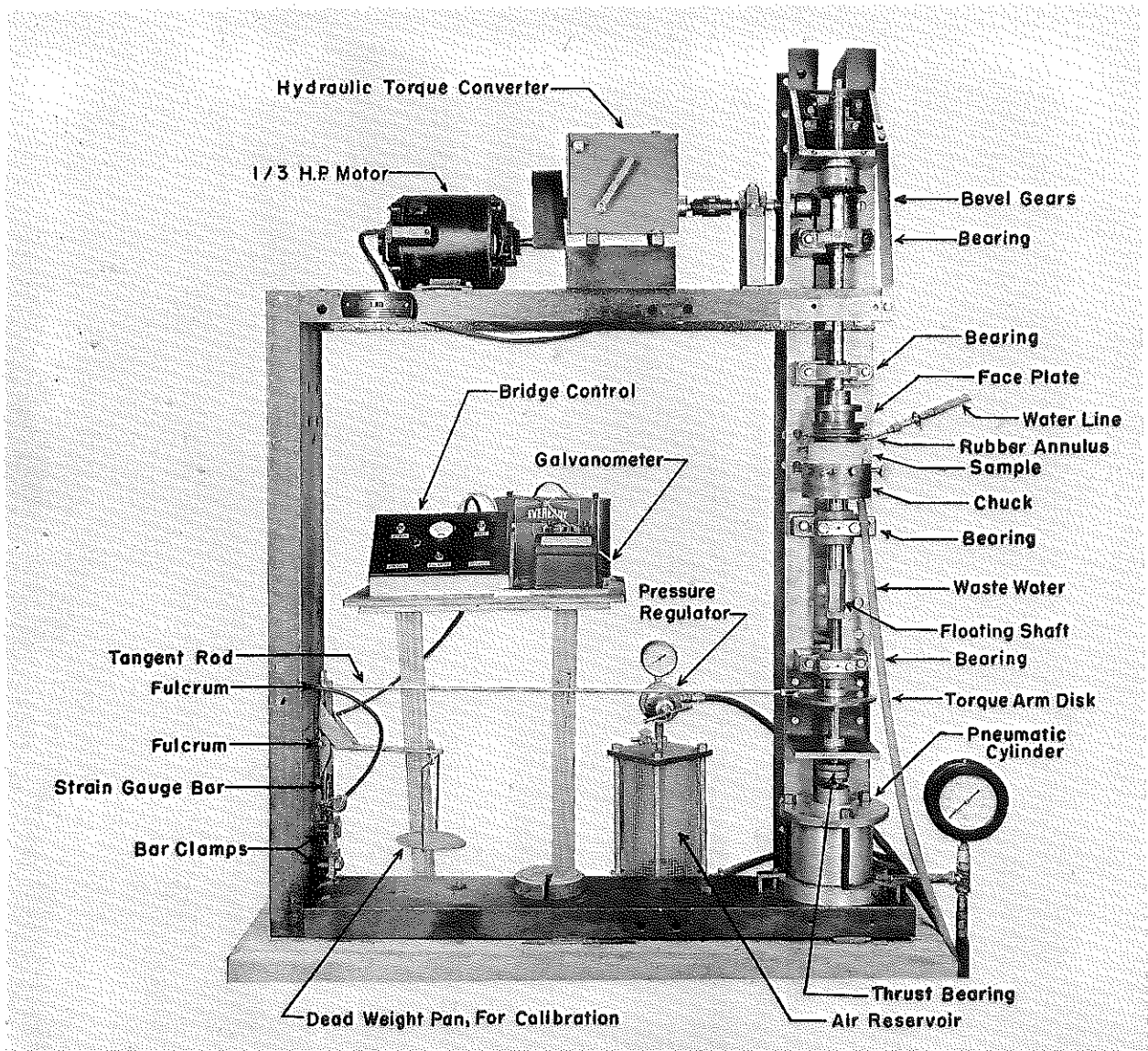


Fig. 5. Friction Measuring Apparatus

EVALUATION OF PAVEMENT SURFACE TYPES

While the immediate objectives of the comparative study of aggregates, in relation to polishing characteristics and the influences of texture on coefficients of friction, was to establish a working hypothesis, the ultimate objective was to evaluate pavement surface types. With this objective in mind, the friction measuring apparatus was designed to accommodate 4-in. diameter pavement cores as well as compacted Marshall Stability specimens. At present, only limited progress has been made in this stage of the investigation. Some of the more general aspects of the problem may be of interest, and they are described briefly.

Bituminous Concrete Using Natural Sand Fine Aggregate

Present practices in Kentucky require 50 percent natural sand in high-type bituminous surfaces. This, of course, is in response to a desire to "build in" skid resistance. While this has apparently alleviated the slickness problem to a considerable degree, no field measurements or specific data are presently available for proper evaluation of the actual benefit gained by this practice in comparison to other alternatives.

Studies on Sand-Asphalt Mixes

For many years Kentucky has used natural sandstone rock asphalt for surfacing and de-slicking treatments. This material has been used also by various research groups elsewhere as a reference or standard in skid resistance studies and, to a considerable extent, has served as a prototype in the development of anti-skid, sand-asphalt, surfacing mixtures. Deficiencies in stability of the natural material have recently imposed restrictions on its use. As a consequence of this, studies on sand asphalt mixes have been instigated.

In addition to studies on sources, blends, and gradations of natural and crushed sands and on stabilities of mixtures, efforts have been made to measure coefficients of friction using the apparatus previously described. Marshall Stability specimens were readily adaptable to the apparatus. The compacted specimens were cured 7 days in air at 80°C. prior to measurement. Following the same general procedure as used for measurements on the rock cores, a series of eight widely differing mixtures gave wet friction coefficients ranging between 0.40 and 0.60. Rock asphalt, by the same method of test, gave a value of 0.53.

While making these tests, it was observed that severe wear or sanding away of the sample occurred immediately after contacting the spinning rubber annules; and, because of this, it is doubtful that this method of testing offers a very realistic evaluation of the friction values that might be expected of the materials after a few years of service in the roadway. However, the value obtained from the rock asphalt is in fairly close agreement with values obtained from actual field measurement (2).

Bituminous Concrete Using Sandstone Aggregate

Although originating as a study of the feasibility of using crushed sandstones as a bituminous paving aggregate, a 30-mile test pavement built in eastern Kentucky in 1951 (3), has shown promising indications of rather high anti-skid qualities. A view of this road is provided in Figure 6. In addition, Figure 7, presents a close-up view of the pavement surface after 7 years in service. Wear in the coarse aggregate particles is evidenced by the fact that they are now slightly recessed below the surrounding matrix. It is also apparent

that the matrix is comprised largely of firmly cemented sand grains and is more resistant to wear than the coarse aggregate particles.

The coefficient of wet frictions, after two years of service and as measured by the trailer method (2), compared favorably with sandstone rock asphalt surfaces of equivalent age and exceeded that of limestone surfaces of lesser age.

Several pavements of this type have been built more recently; and, while specific data regarding slipperiness is not available, they exhibit the same generally sandy texture and tendency for the coarse aggregate particles to undergo coarse wear.

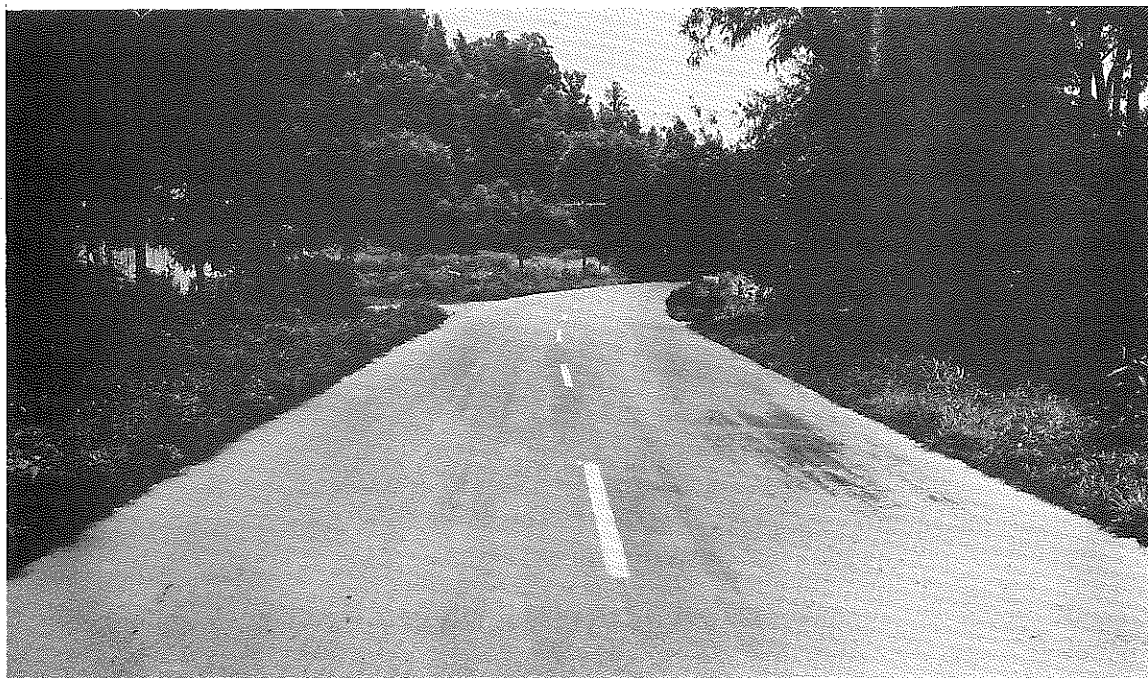


Fig. 6. Ky. 30, Salyersville-Jackson, Constructed with Crushed Sandstone Aggregate in 1951



Fig. 7. Close-up View of Sandstone, Bituminous Concrete after 7 years, Note Wear of Coarse Aggregate Particles. (Ky. 30, Salyersville-Jackson)

DEVELOPMENT OF A FIELD TEST METHOD

Because of the need for actual field testing and the variety of pavement types in Kentucky, efforts have been made very recently to adapt a 1957 Ford automobile, already equipped with instrumentation for evaluating road-roughness (4), to measure and monitor pavement slipperiness. The idea is basically that of the skewed wheel, only in this case, the skew is provided by increasing the toe-in of the front wheels. The drag induced thereby is eventually translated into compression of the tie-rod; and this compression or thrust is measured by means of a ring-type load-cell and is charted on an oscillographic recorder, Figure 8. The position of the load-cell is illustrated in a schematic plan view of the front wheel system of the vehicle, Figure 9.

The normal toe-in for this vehicle is 1/16 inch measured from tread-to-tread. In trial runs, this has been increased to as much as 1-3/4 inches, but lesser degree of skew seemed more desirable. Excessive wear on the tires must be accepted or else quick-adjusting linkages will have to be installed in each of the tie-rods to permit normal driving between measurements.

Results obtained from trial runs thus far have been very encouraging. Pavement types are easily distinguished. Figure 10 shows chart records made during dry weather contrasted against records from the same pavements obtained during a light rain.

As a comparative method of monitoring slipperiness, the idea offers considerable convenience, particularly if advantage is taken of rainy weather.

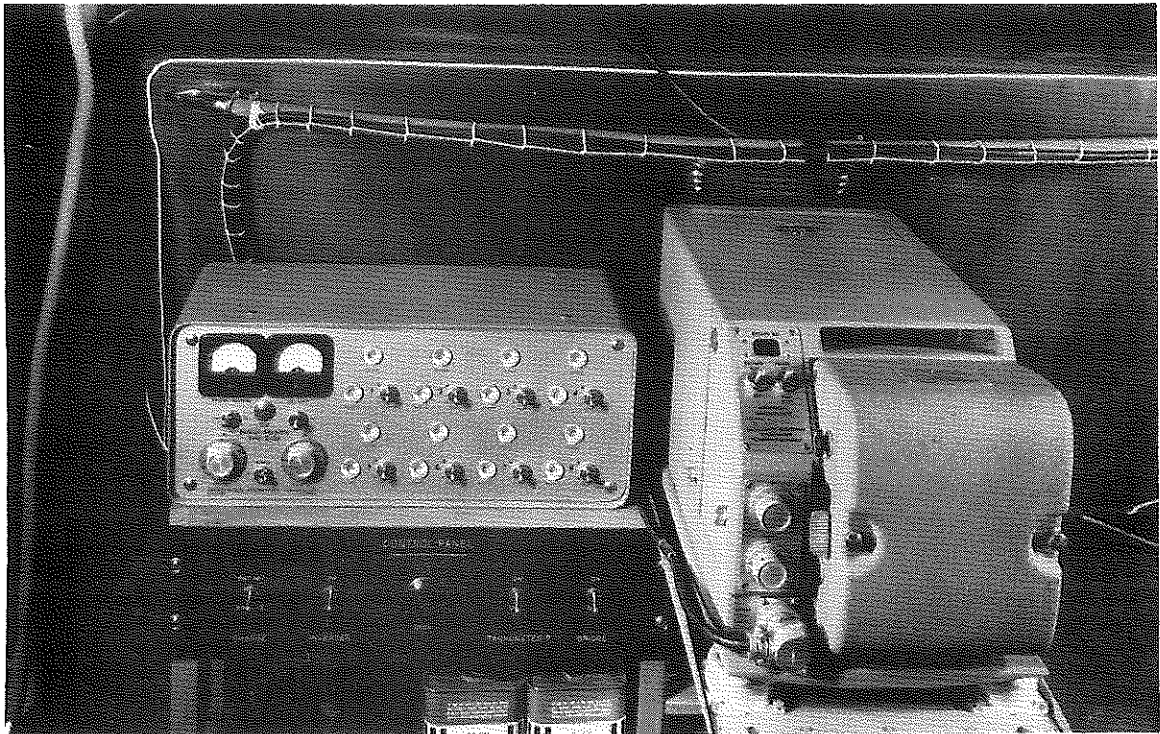


Fig. 8. Automatic Oscillographic Recorder and Strain Gauge Bridge Balance, Mounted in Passenger Car, Used with Satham Accelerometers and Strain Gauge Load Cell.

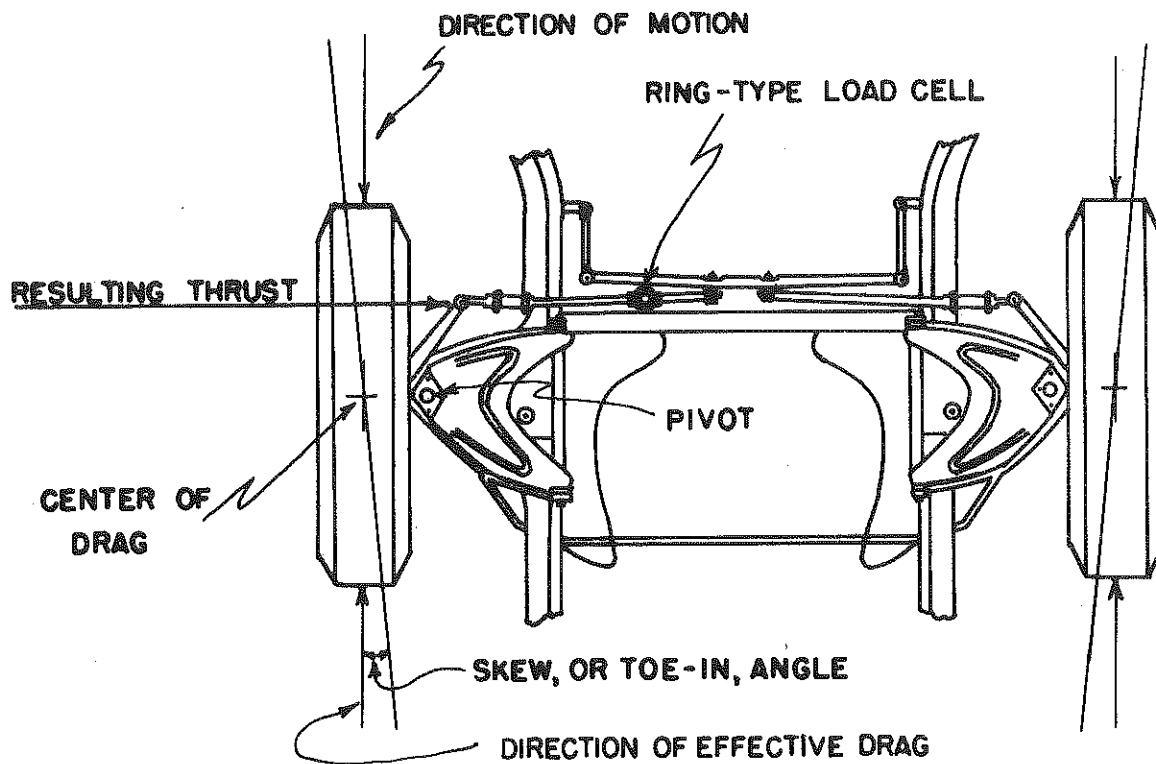


Fig. 9. Plan View of Front End of Passenger Car Showing Position of Ring-type Load Cell in Left Tie-Rod. Increased Toe-in Creates Drag which is Eventually Translated into Thrust or Compression in the Tie-Rod. Deflections Induced in the Load-Ring are Measured by SR-4 Strain Gauges. Oscillographic Recorder Permits Continuous Monitoring of Drag or Comparative Frictional Resistance.

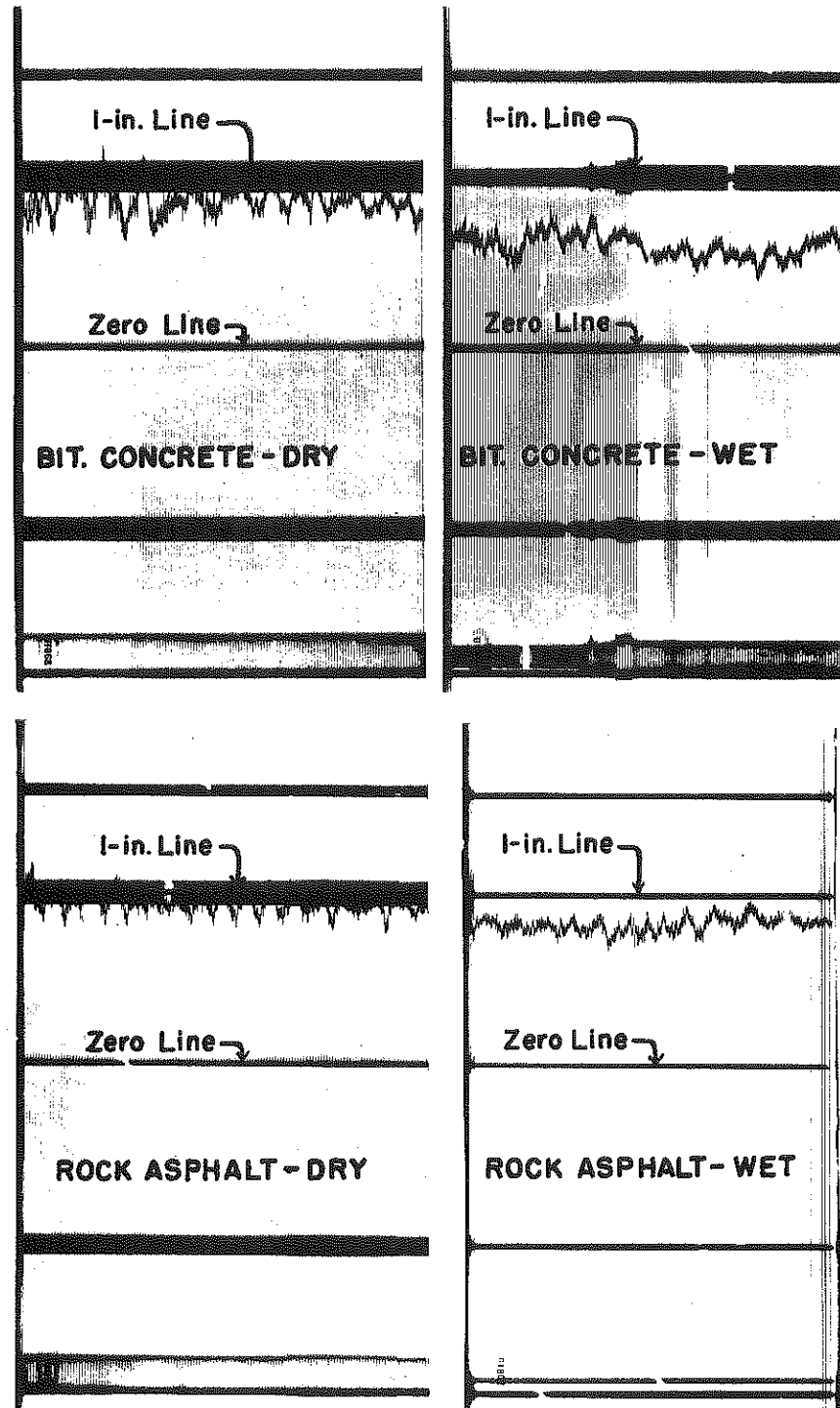


Fig. 10. Pictures of Actual Preliminary Chart Records, Comparing Dry and Wet Conditions of Different Types of Pavement.

FUTURE STUDIES

It is anticipated that further developments in the adaptation of an ordinary automobile to skid-resistance measurements will permit continuous monitoring of roads under near-normal driving conditions. Calibration and comparison of the method may be established by the stopping distance method, the accelerometer method, or by testing pavement cores. Since measurements on wet pavements are the more pertinent to the problem, considerable difficulty may be avoided by awaiting suitable weather conditions.

It is intended, by this means, to obtain comparative data from various types of roads and surfaces and to provide a rational basis for pavement surface design. It is also intended by this means, to search out critically slick roads or particular locations in need of de-slicking treatment.

REFERENCES

1. Stutzenberger, W. J., and Havens, J. H.; "A Study of the Polishing Characteristics of Limestone and Sandstone Aggregates in Regard to Pavement Slipperiness," presented at the 37th Annual Meeting of the Highway Research Board, January 1958.
2. Whitehurst, E. A., and Goodwin, W. A.; "Pavement Slipperiness in Tennessee," Proceedings, Highway Research Board, Vol. 34, 1955.
3. Williams, E. G., and Gregg, L. E.; "Evaluation of Sandstones as an Aggregate in Plant Mix Bituminous Pavements," Proceedings, Association of Asphalt Paving Technologists, Vol. 22, 1953.
4. Gregg, L. E., and Foy, W. S.; "Triaxial Acceleration Analysis Applied to Evaluation of Pavement Riding Qualities," Proceedings, Highway Research Board, Vol. 34, 1955.